USING MASS FLUX ANALYSIS TO IMPROVE SITE CHARACTERIZATION AND REMEDY SELECTION

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Outline

- Introduction to Mass Flux & Mass Discharge
- Stratigraphic Flux
  - Depositional Environment
  - Facies Permeability
- Hydraulic Conductivity Profiling Tools
- Case Studies

Why Does Flux Matter?

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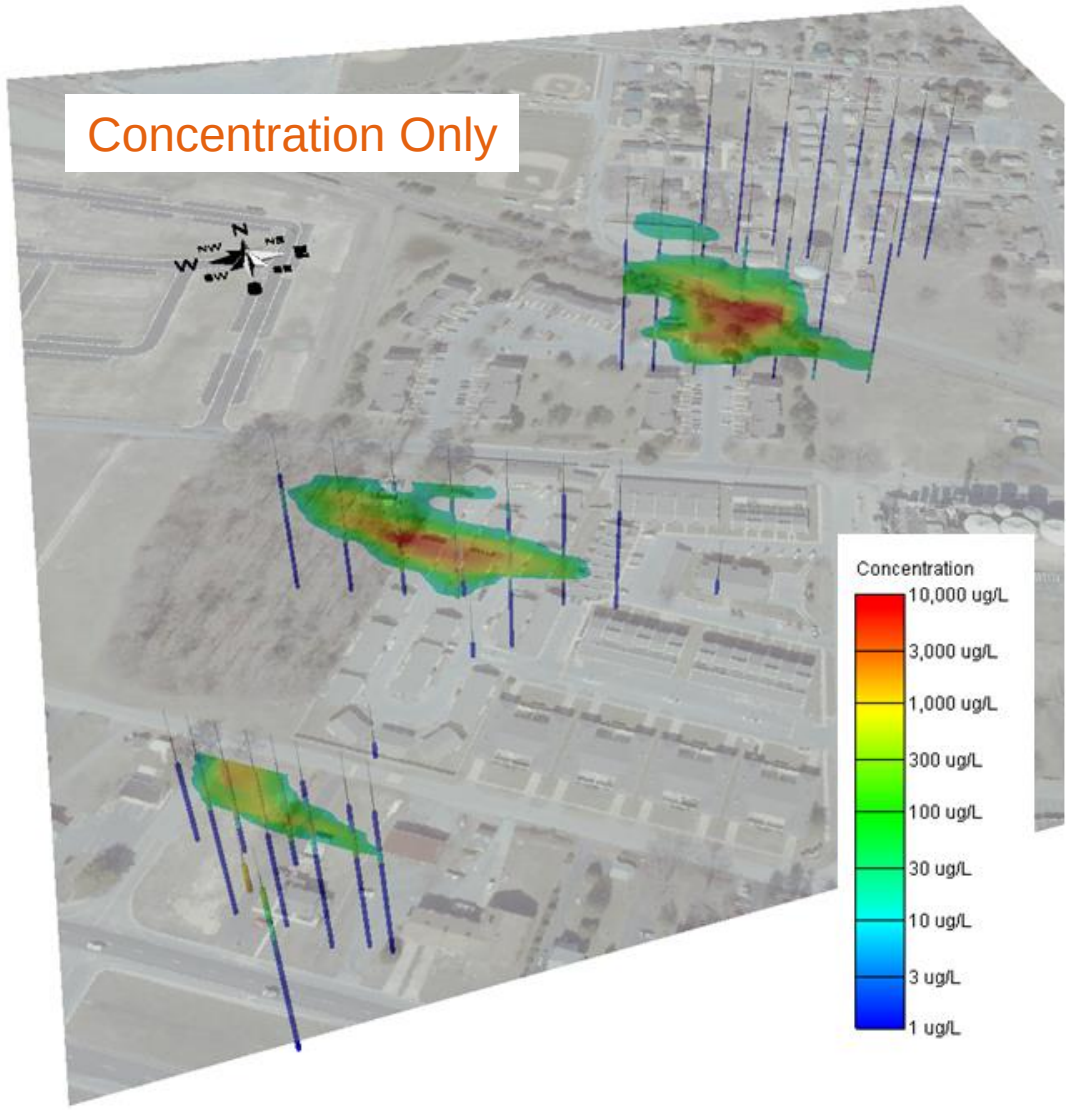
Contaminant distribution is only half of the story

- Need to distinguish mass in high permeability and low permeability zones to understand mass transport

Mass Flux describes the concentration of contaminant movement

- Understand risk
- Evaluation of focused remedy



Mass Flux and Mass Discharge

Mass Flux - the mass flow across a unit area

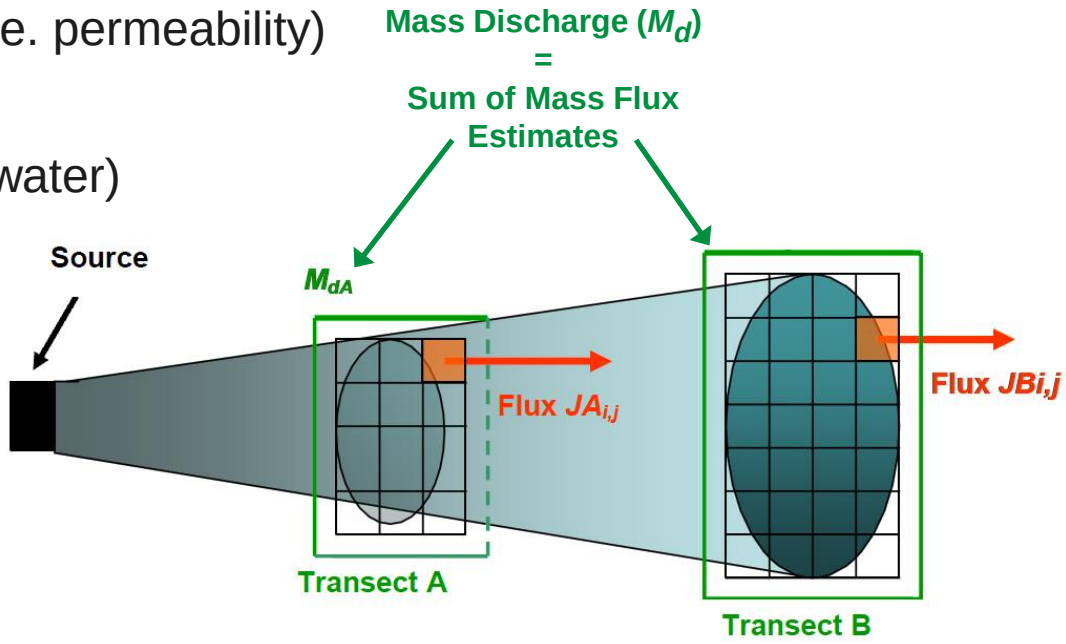
$J = K\,i\,C$ (mass/time/area)

- K = Hydraulic Conductivity (i.e. permeability)
- i = Hydraulic Gradient
- C = Concentration (in groundwater)

Mass Discharge – integrated mass flux

$M_d = \int_A J\,dA$ (mass/time)

- J = Mass Flux
- A = Total area

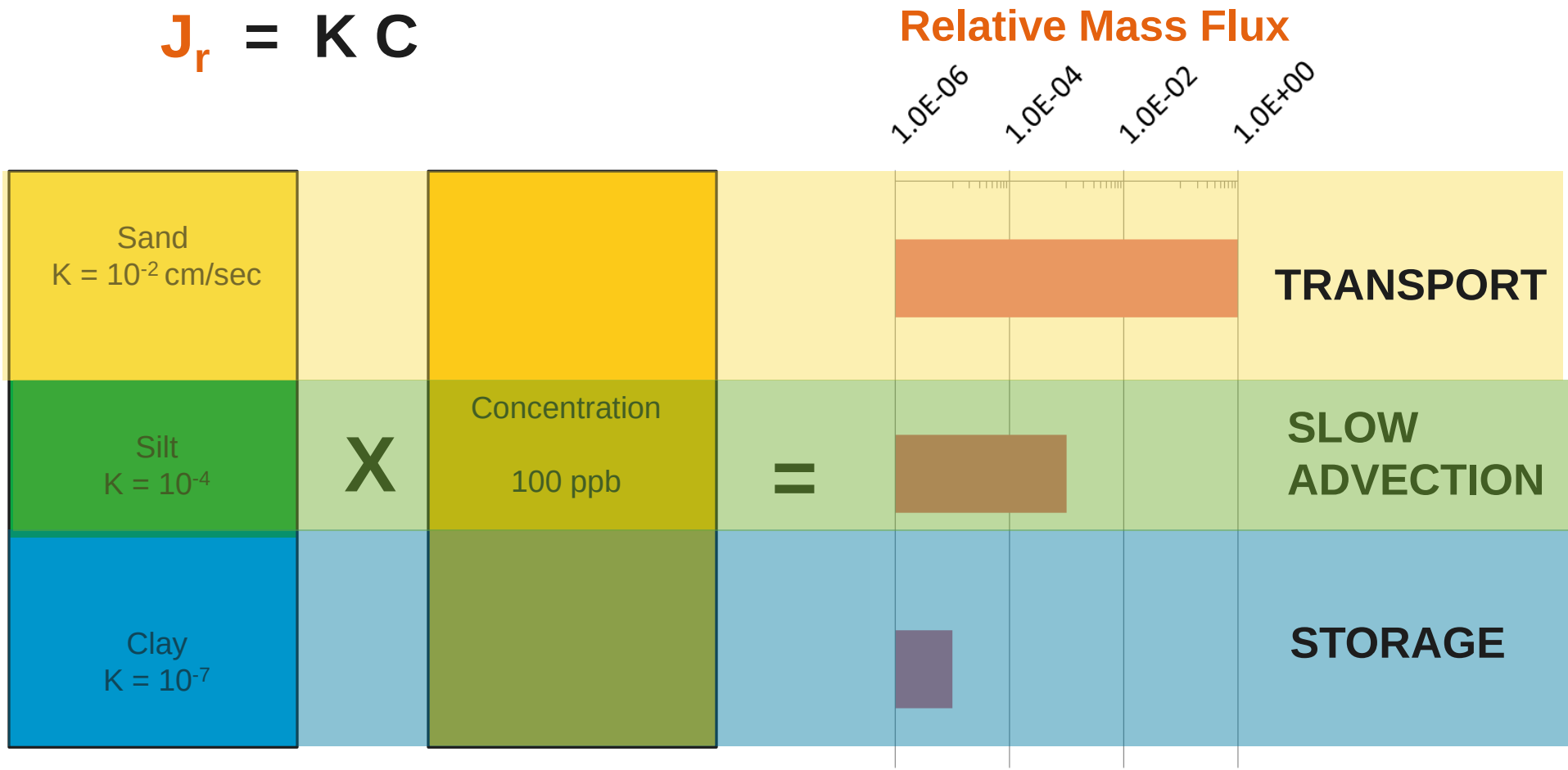


Adapted from ITRC, 2010

Relative Mass Flux

We can drop the gradient term, as K varies >> i

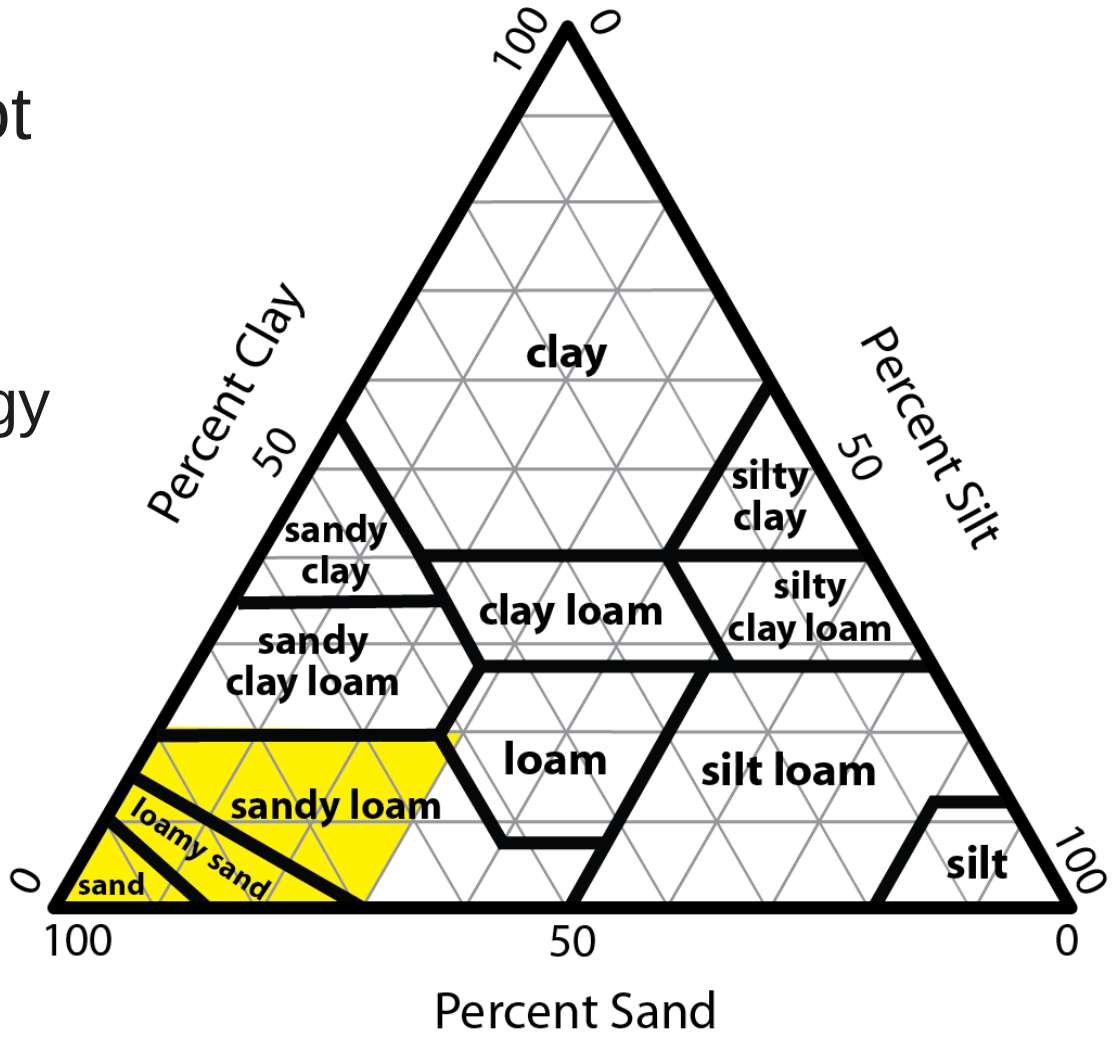
$$J_r = K\,C$$



Where the Groundwater Flows…

Most soil types are not aquifer material

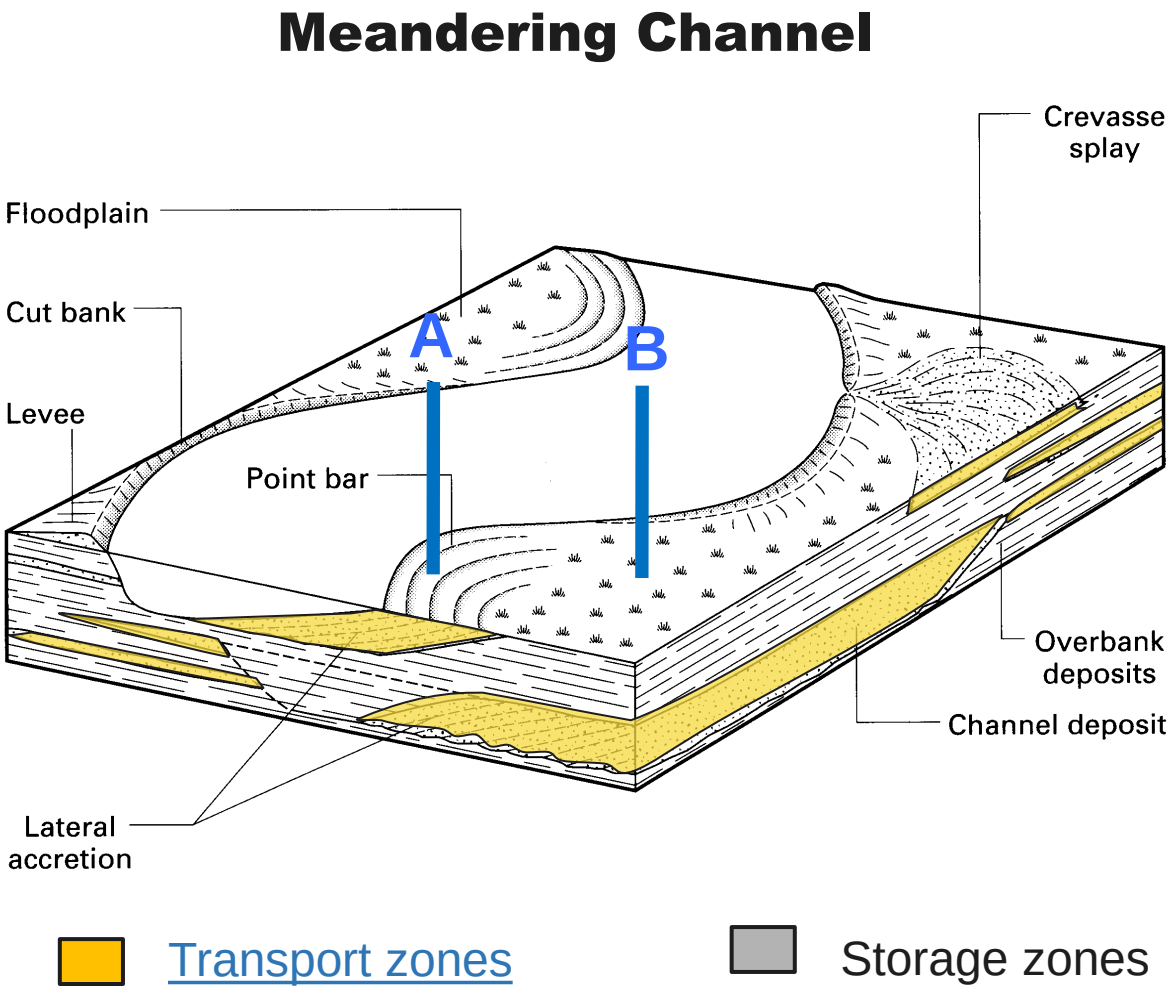
- The aquifer matrix is laid down in high-energy environments
- High-energy environments are heterogeneous and anisotropic



Stratigraphic Flux

Link mass flux analysis with classical geological interpretation to describe the 3-D aquifer architecture

- Focus evaluation on zones that matter
- Helps prioritize remediation efforts



Facies and Permeability

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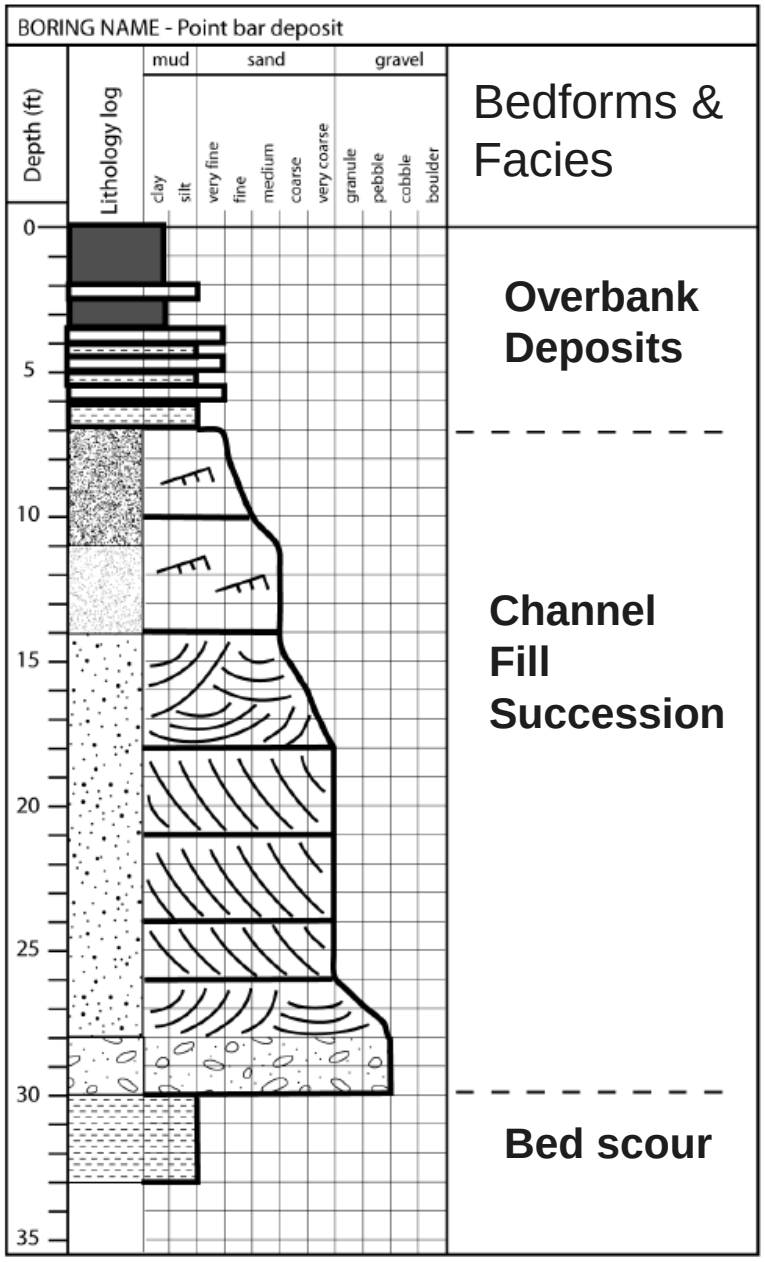
Detailed soil descriptions key:

- High permeability, coarse grained at base
- Decreasing permeability & grain size toward top
- 5+ orders of magnitude variability in K

A

Hydraulic Conductivity (cm/s)

$<10^{-5}$	Storage
$\sim10^{-4}$	Slow Advection
$\sim10^{-3}$	Transport
$\sim10^{-2}$	
$>10^{-1}$	Fast Transport
$<10^{-5}$	Storage



Basis for Interpolating Borings

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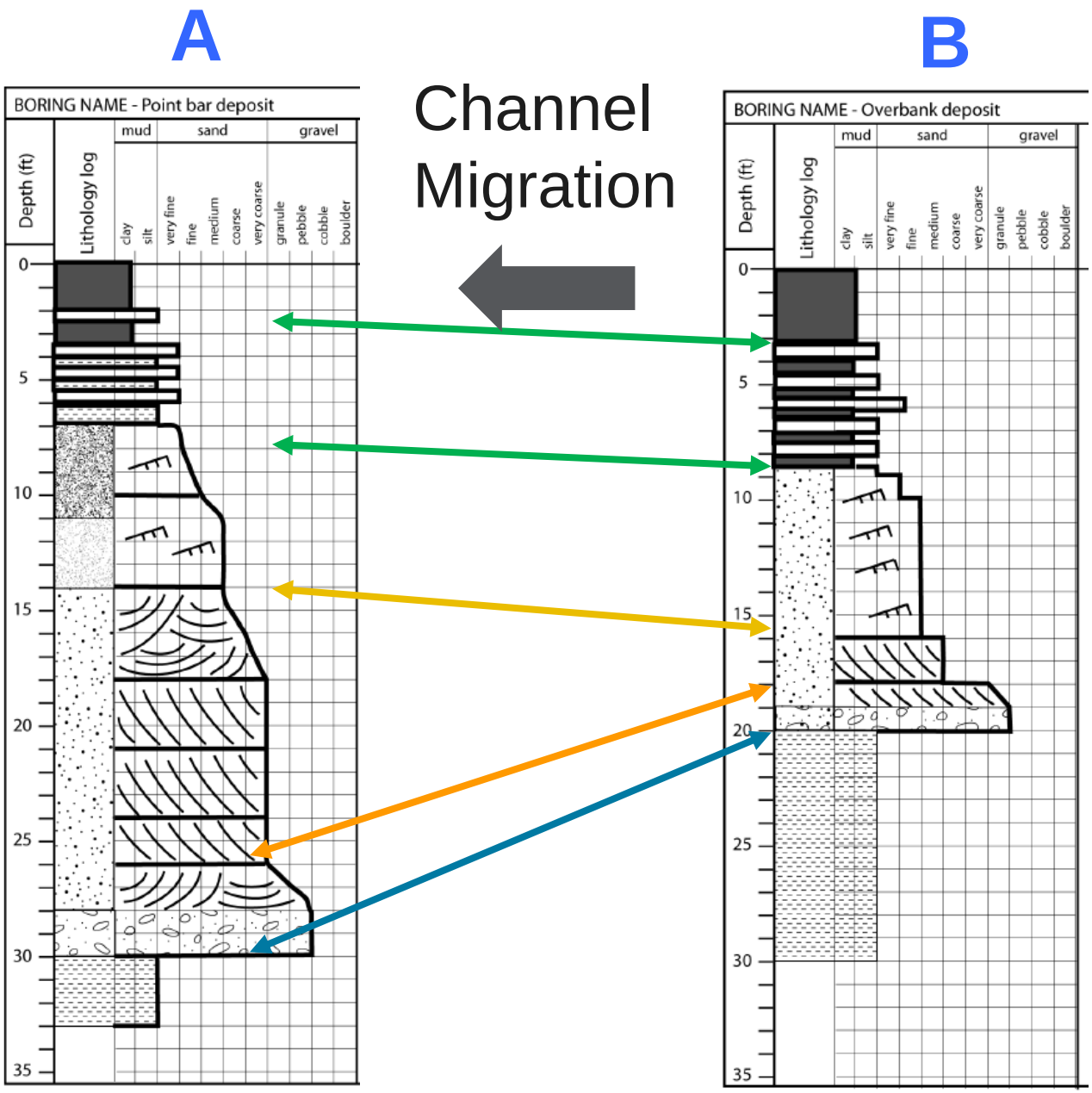
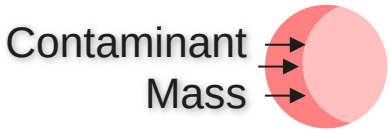
Accretion from right to left:

- Depositional environment allows for better interpretation between borings
- Provides first basis for the interpretation of stratigraphic flux – transport vs storage

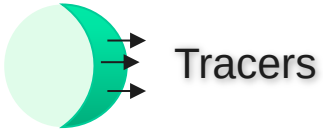


Measurement of Mass Flux and Mass Discharge

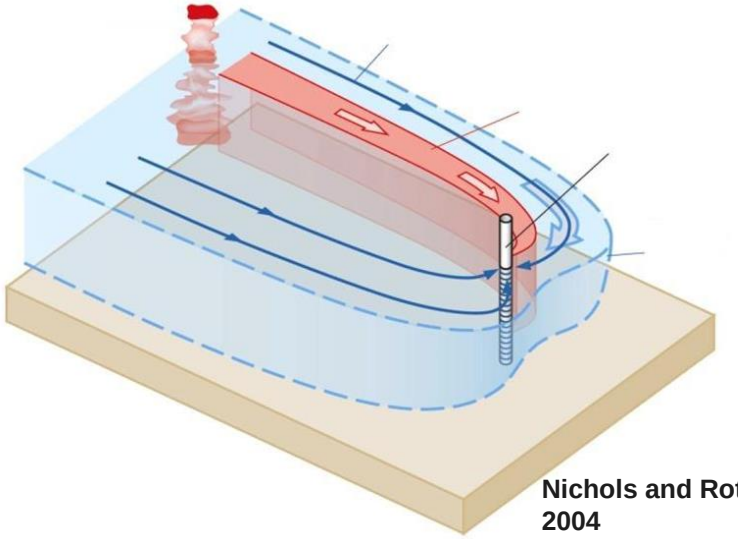
Passive Flux Meters



ENVIROFLUX



Well Capture



Nichols and Roth, 2004

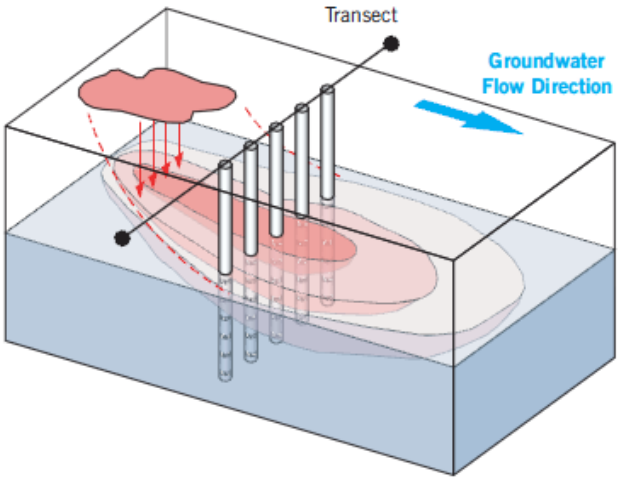
Transect Methods

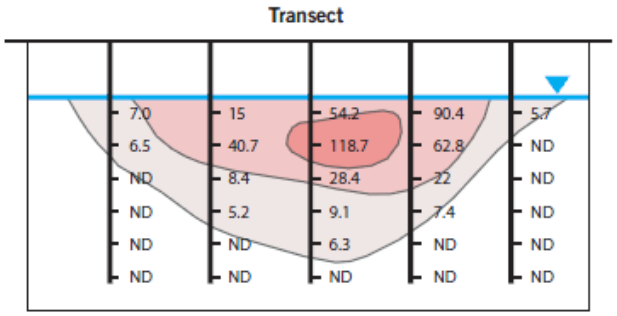
Traditional Transect Method

1. Transect perpendicular to plume
2. At each sample interval collect:
   - Groundwater analytical (C)
   - Hydraulic Conductivity (K)
3. Calculate J and M_d

Time consuming and of limited resolution:

- Conductivity measurements typically bias low
- averaged across several feet





$J = K\,i\,C$

7.0	15	54.2	90.4	5.7
6.5	40.7	118.7	62.8	0
0	8.4	28.4	22	0
0	5.2	9.1	7.4	0
0	0	6.3	0	0
0	0	0	0	0

$Md = \int_A J\,dA$

Nichols and Roth, 2004

K Profiling Tools

Geoprobe Hydraulic Profiling Tool (HPT):

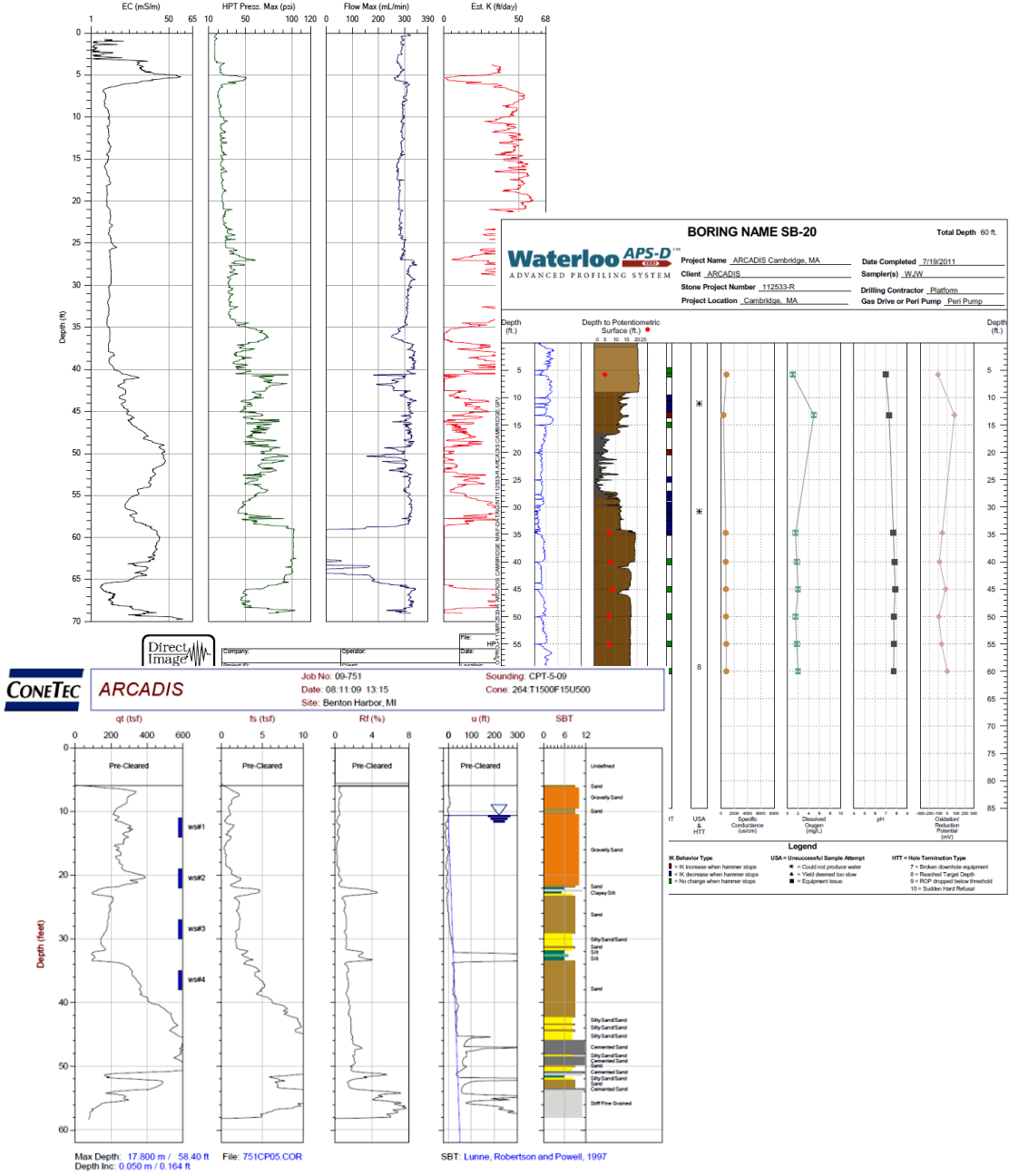
- Inject 200-300 ml/min of water and records aquifer response

Waterloo Advanced Profiling System:

- Similar approach as HPT, can collect groundwater samples in same push

CPT Pore Pressure:

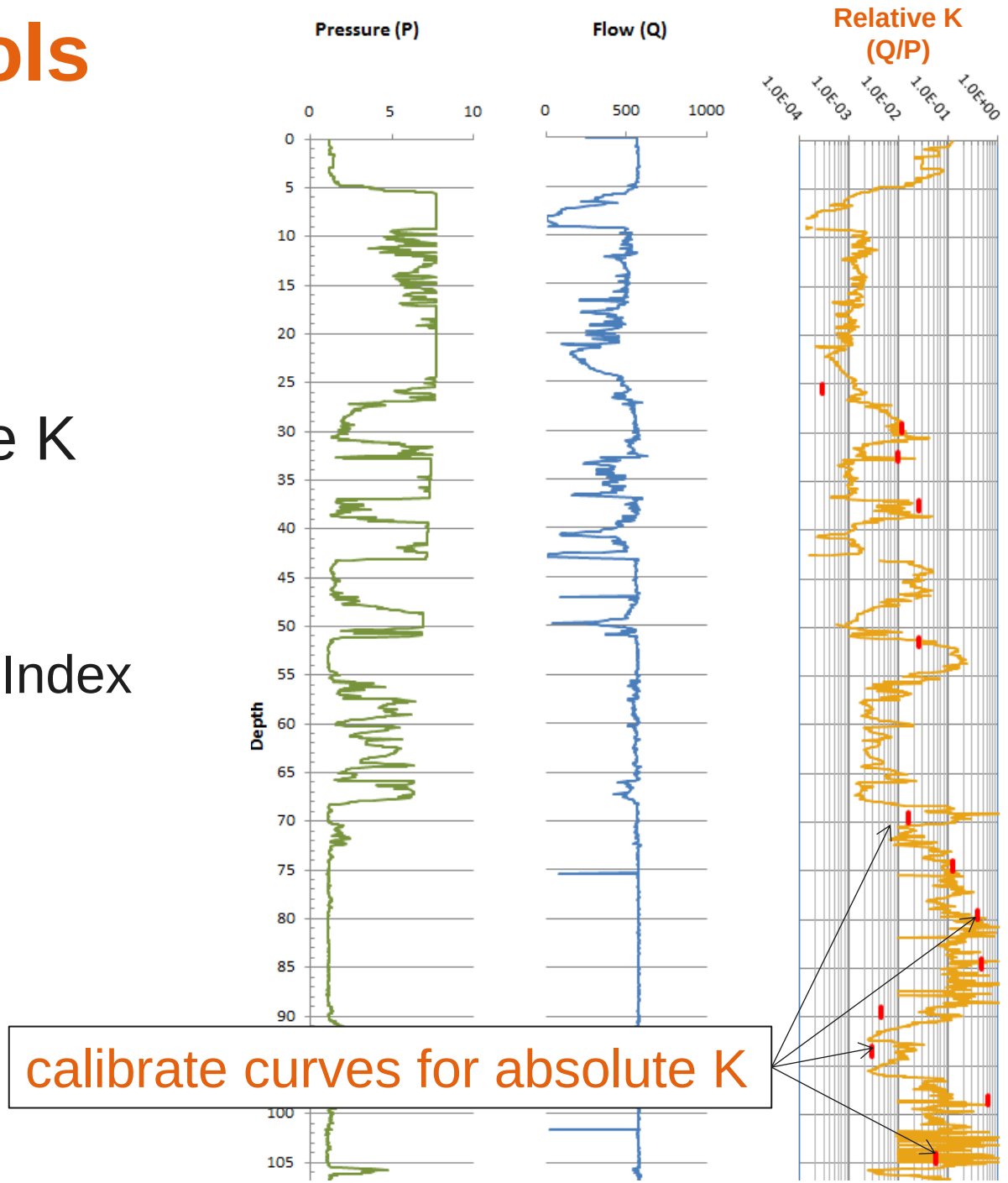
- Ambient pressure response to cone advancement



K Profiling Tools

Map facies and permeability with continuous relative K profile:

- HPT – Est. K (Q/P)
- Waterloo Profiler – Index of K



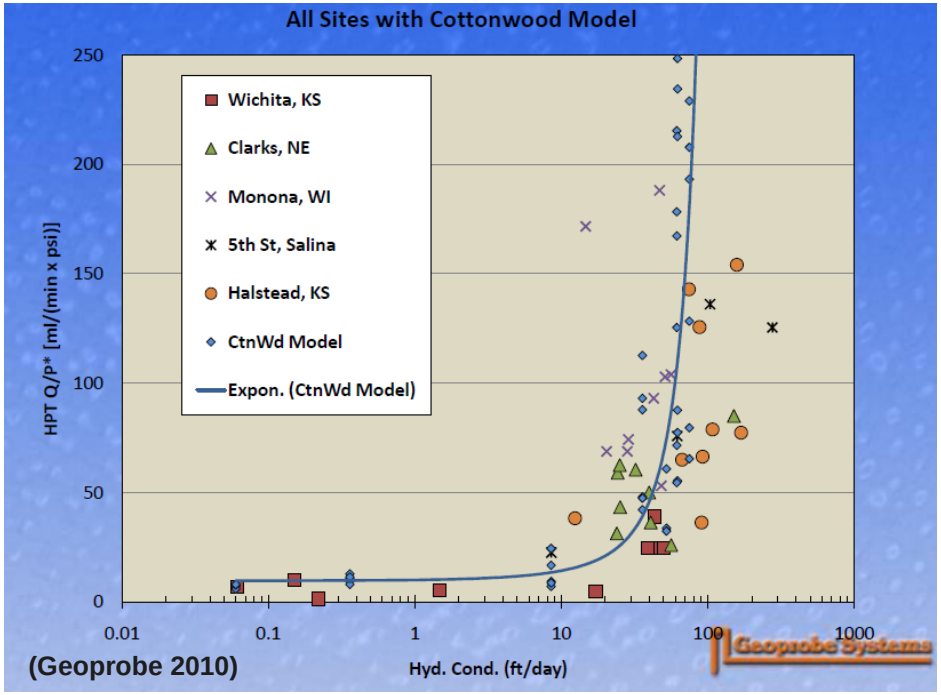
The K Challenge

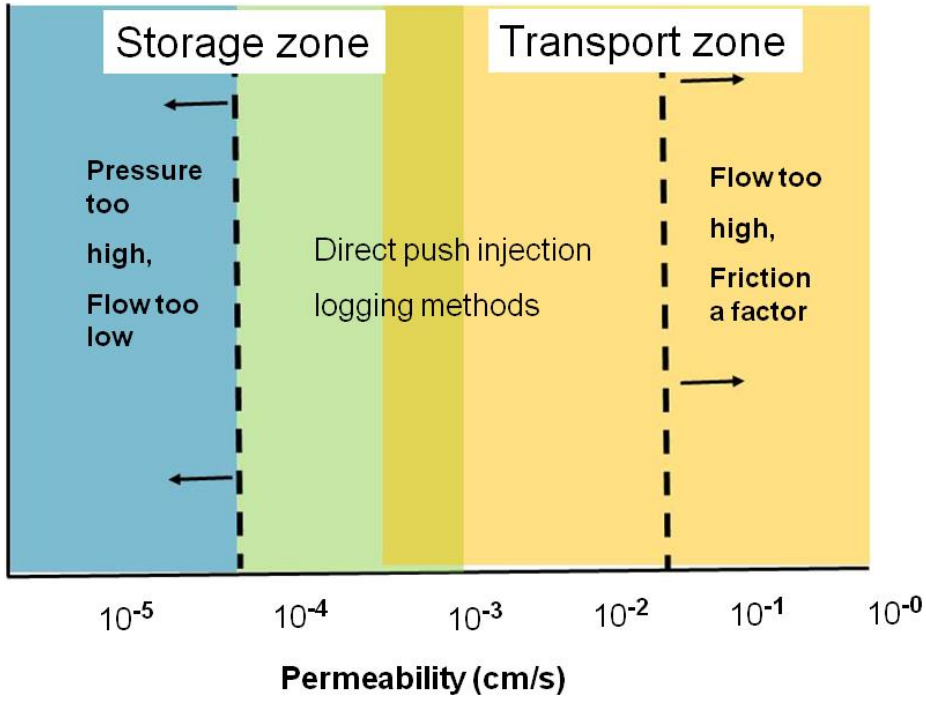
Hydraulic profiling tools easily separate:

- Transport zones from storage zones

Estimate absolute K in relatively small window of conductivity:

- ~ 10^{-4} to 10^{-2} cm/s
- Slow advection to low-end of transport range





Groundwater Concentration

Transport Zones

Vertical aquifer profiling

- Direct Push: screen point sampler
- Sonic: temporary well / packer assembly
  - Drilling with water requires dye
- Traditional (Augers): temporary wells, Simulprobe
- Waterloo Profiler, HPT-GW

Storage Zones

Saturated soil sampling

- Estimate groundwater concentration based on partitioning or leaching method

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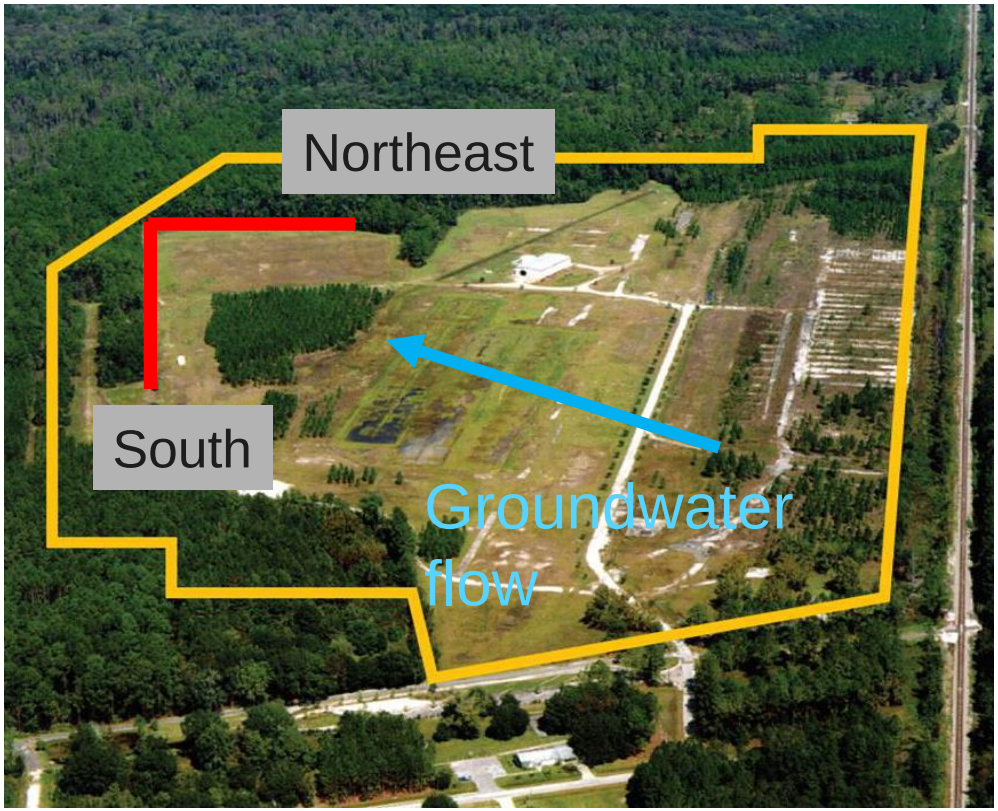
Case Study: Flux Based Optimization of P&T System

Scope

Optimize capture of existing P&T system

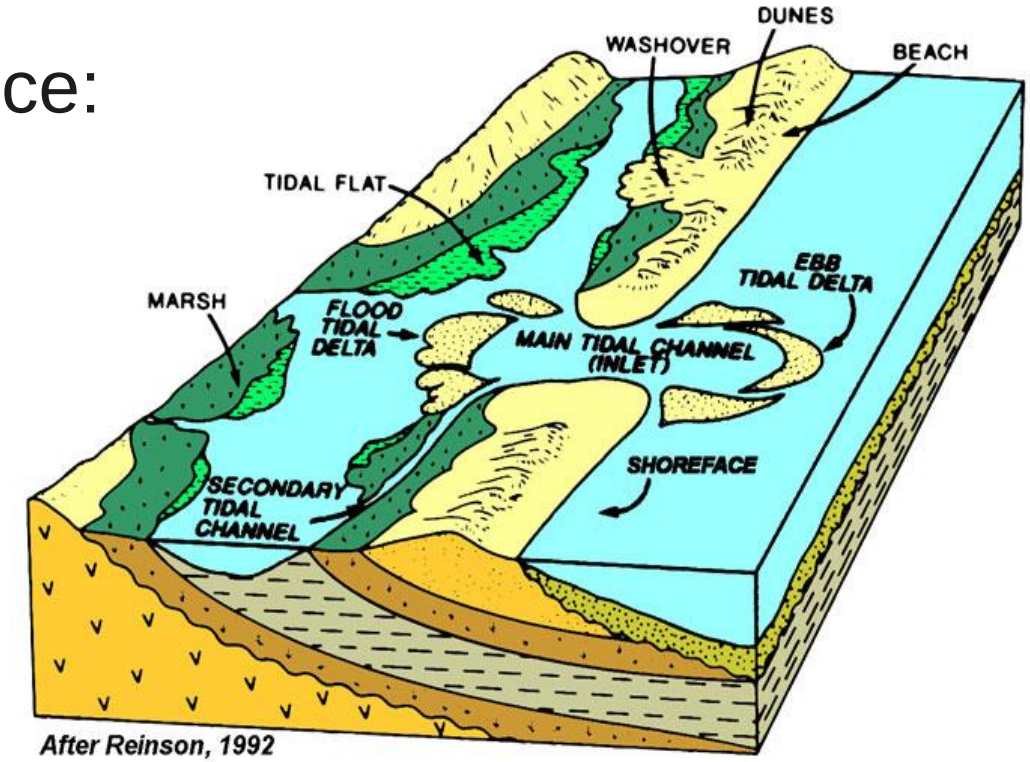
- Stratigraphic flux transect around northwest corner of property
- HPT for relative K
- Vertical aquifer profiling for concentration



Geologic Setting

Sea Island Section of Atlantic Coastal Province:

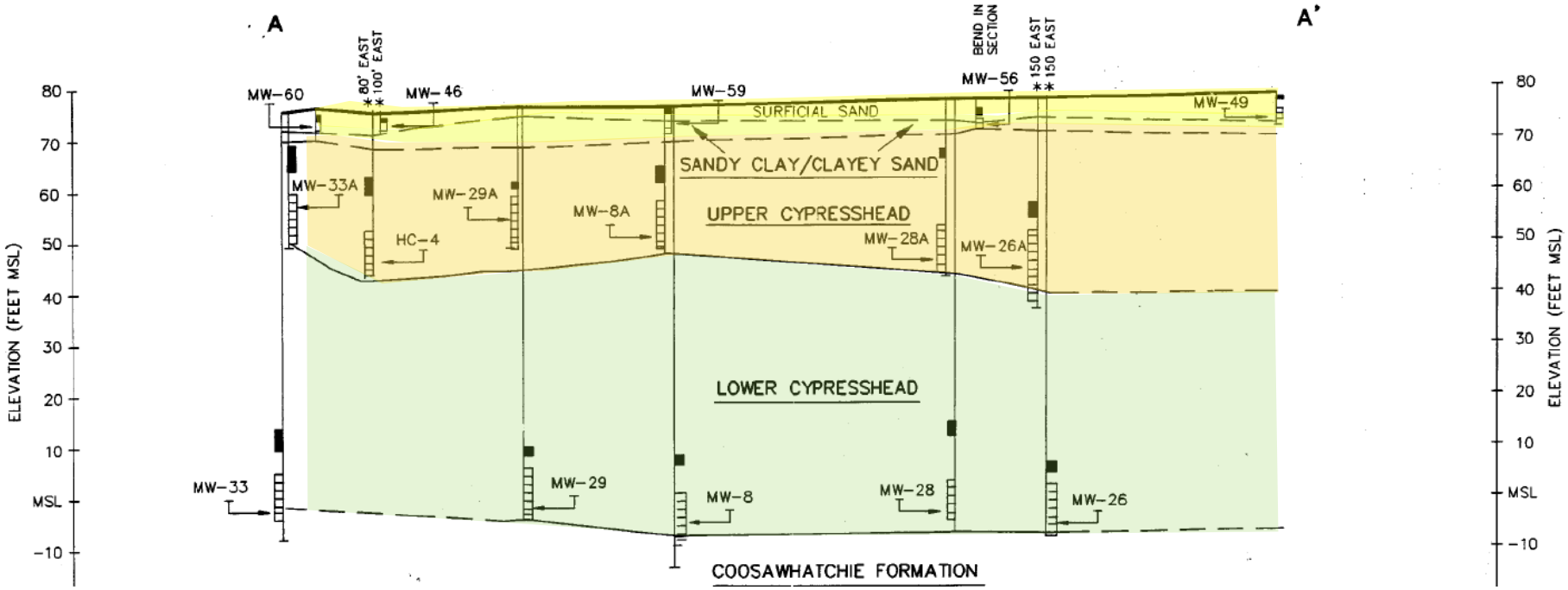
- barrier islands
- salt marsh deposits
- streams



Geologic Setting

Cypresshead Formation:

- Upper – “massively bedded” fine sand
- Lower- greater clay and silt fraction



Hydraulic Profiling

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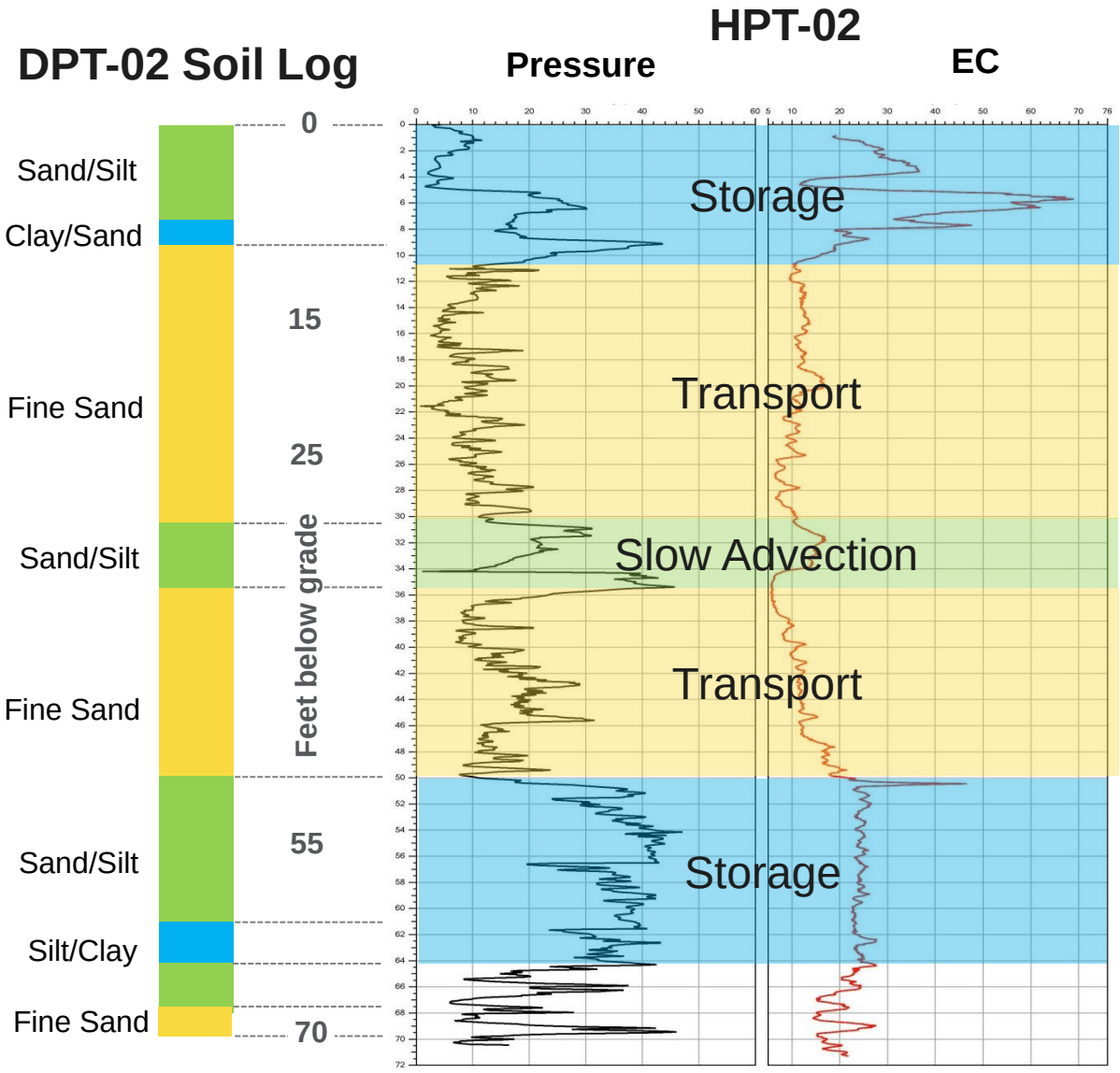
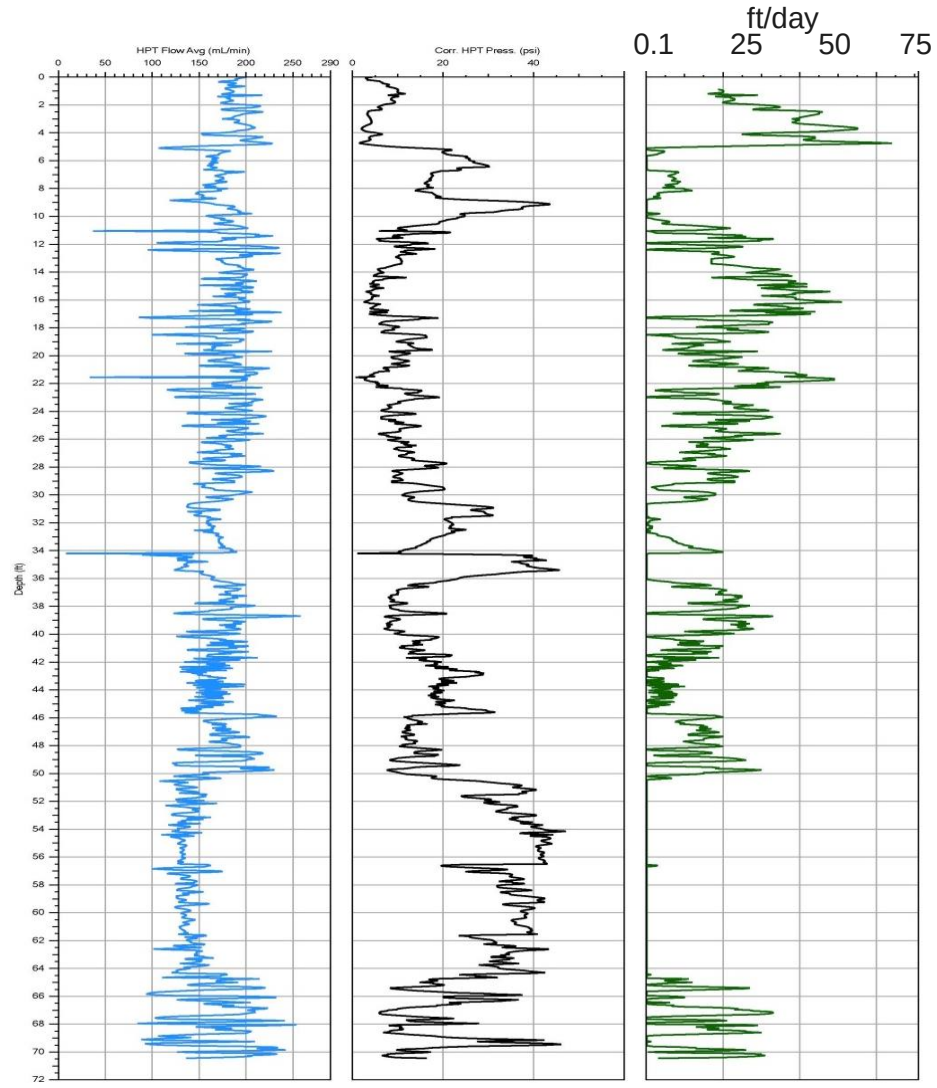
Geoprobe® HPT Tool

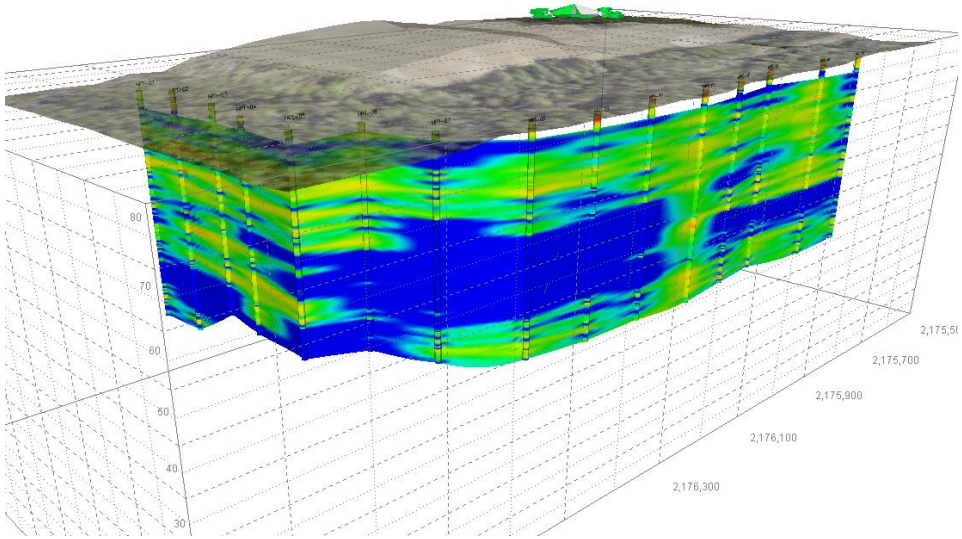


Relative K

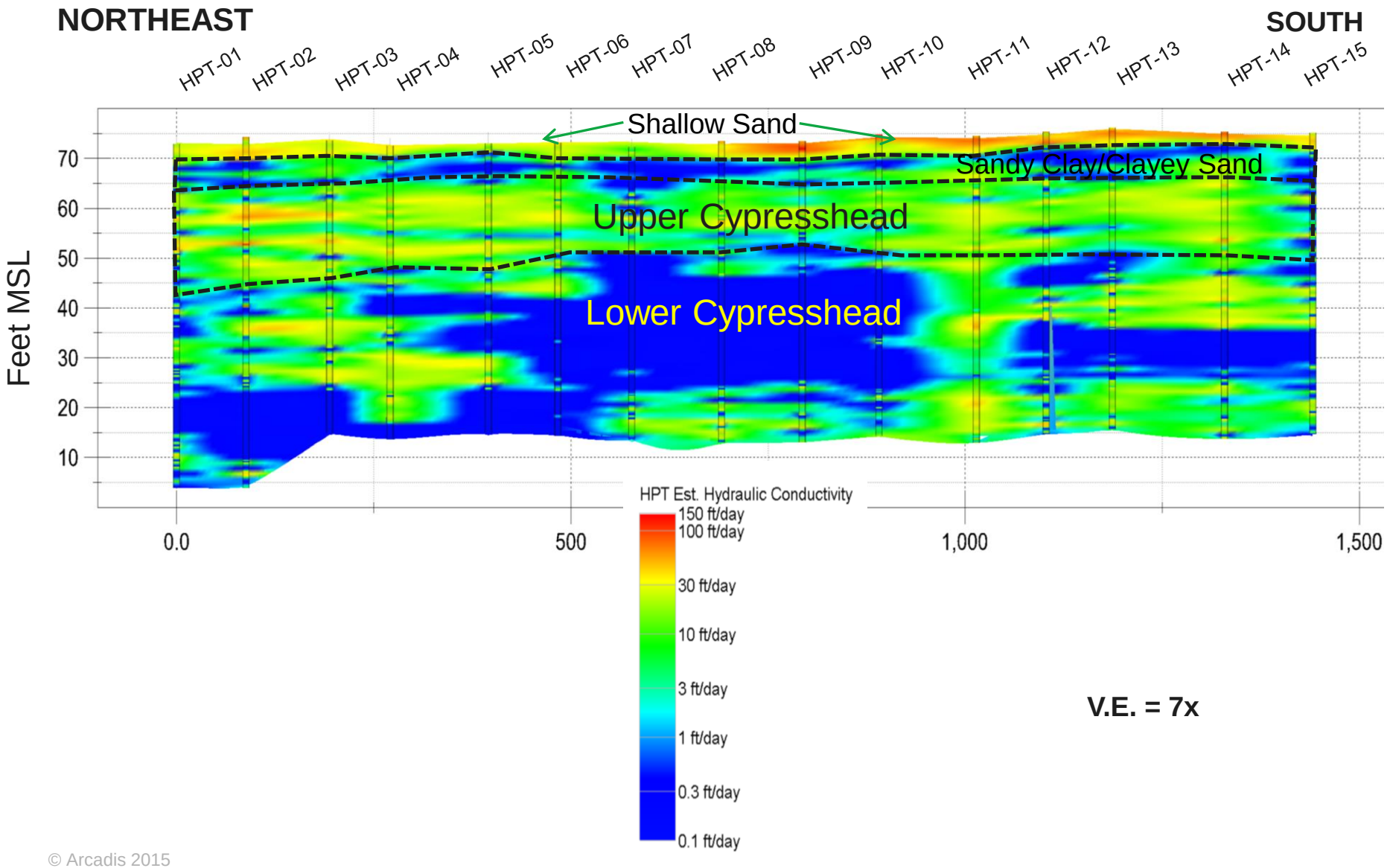
Flow (Q) / Pressure (P) = Est. K (Q/P)



- Q/P corrected based on empirical relationship with slug test data developed by Geoprobe



Stratigraphic Correlation



Naphthalene (ppb)

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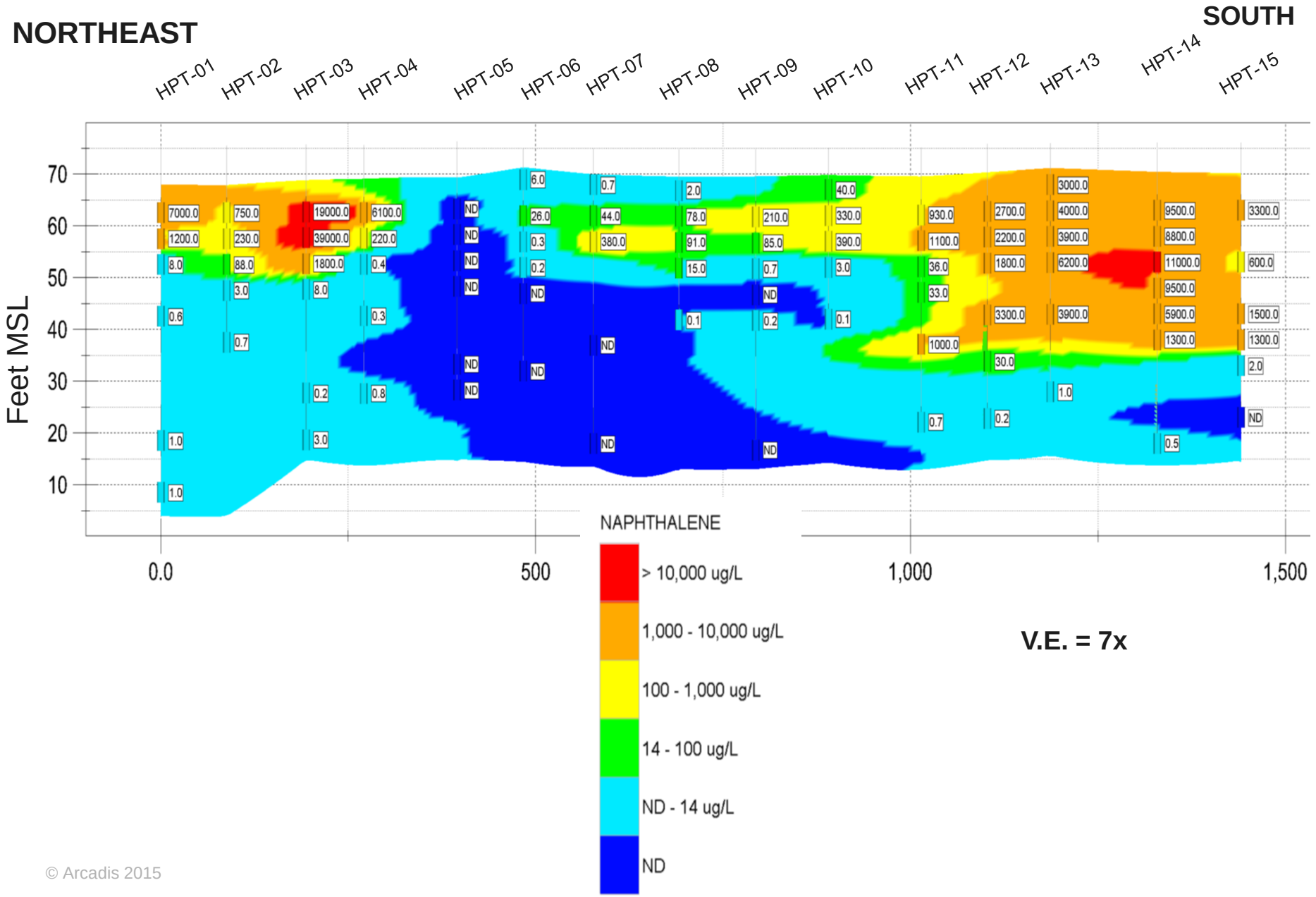
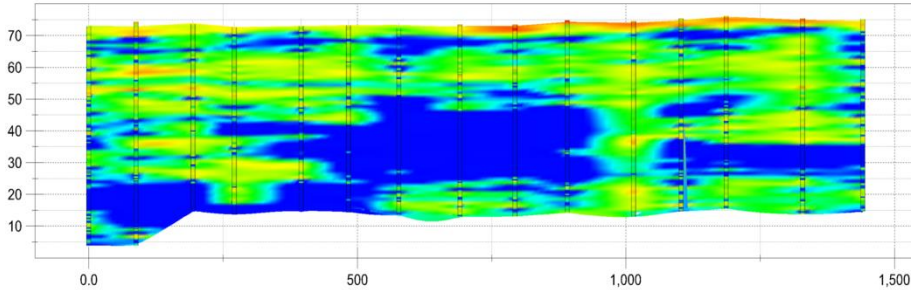


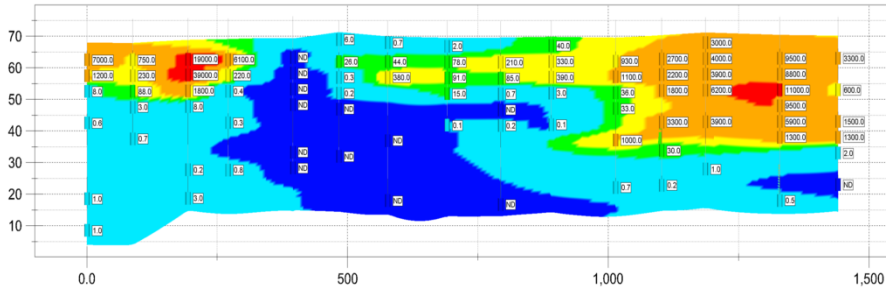
Stratigraphic Flux

Hydraulic Conductivity (K)



X

Concentration (C)



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Stratigraphic Flux

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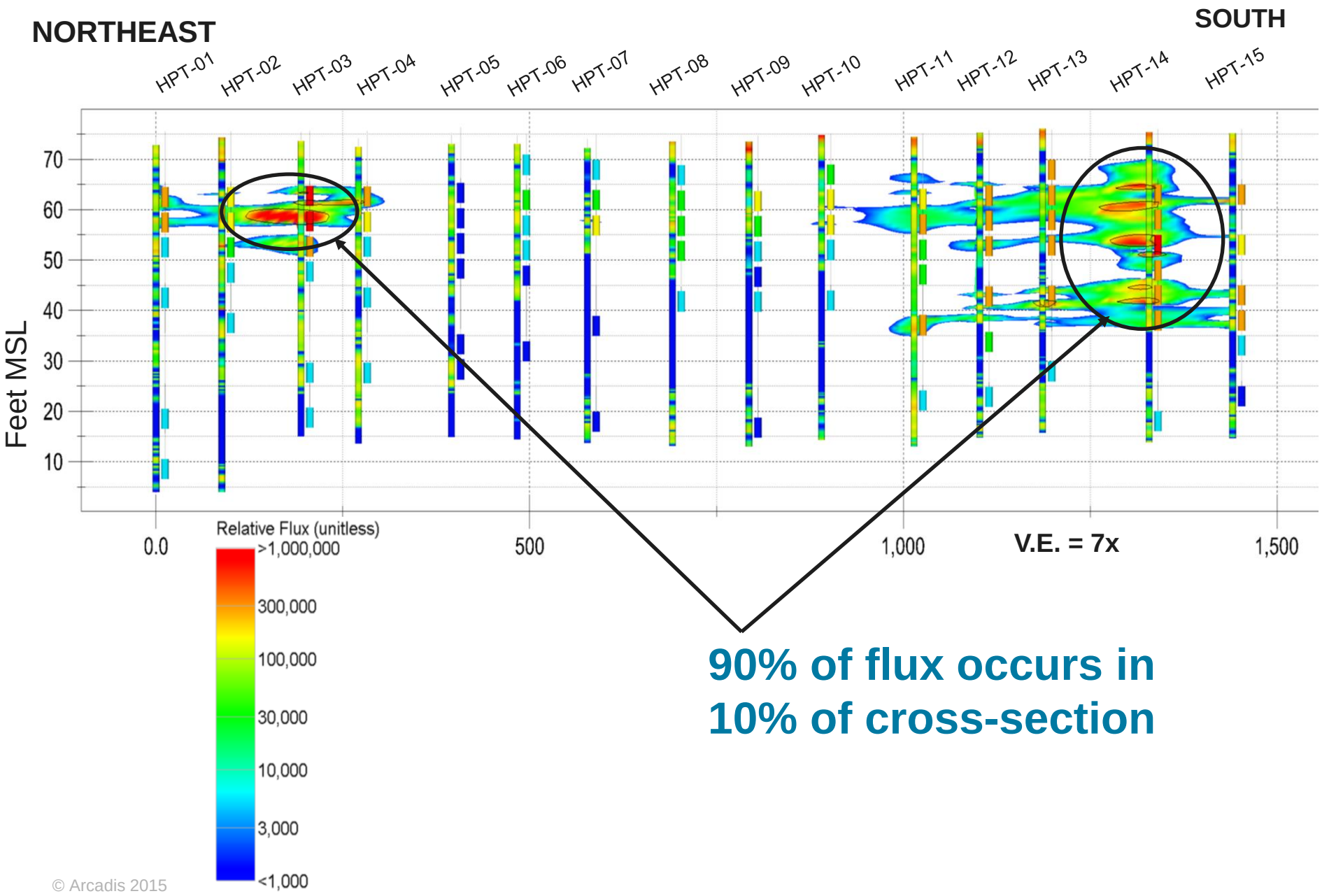

90% of flux occurs in 10% of cross-section

Stratigraphic Flux

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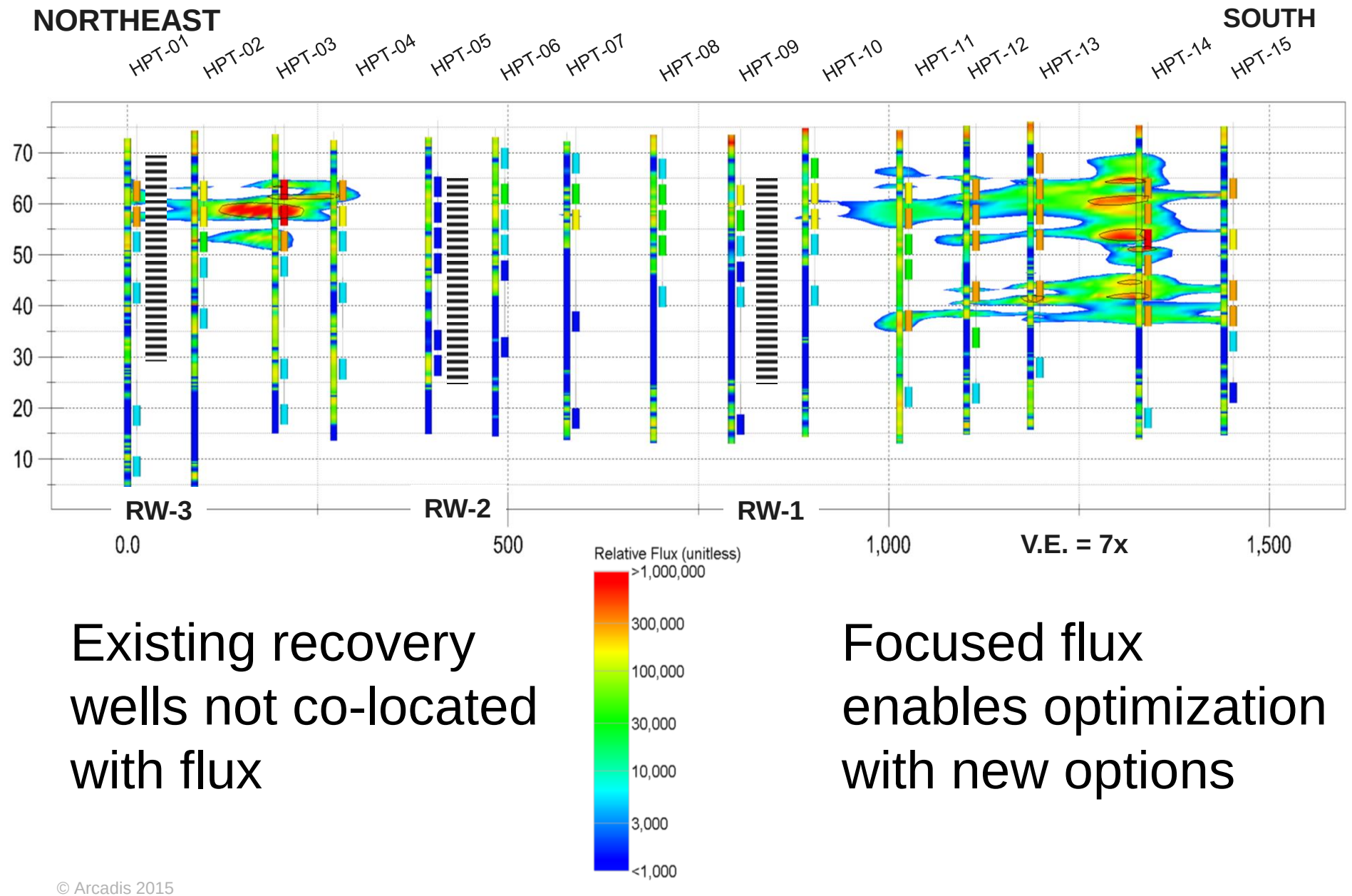

Existing recovery wells not co-located with flux

Focused flux enables optimization with new options

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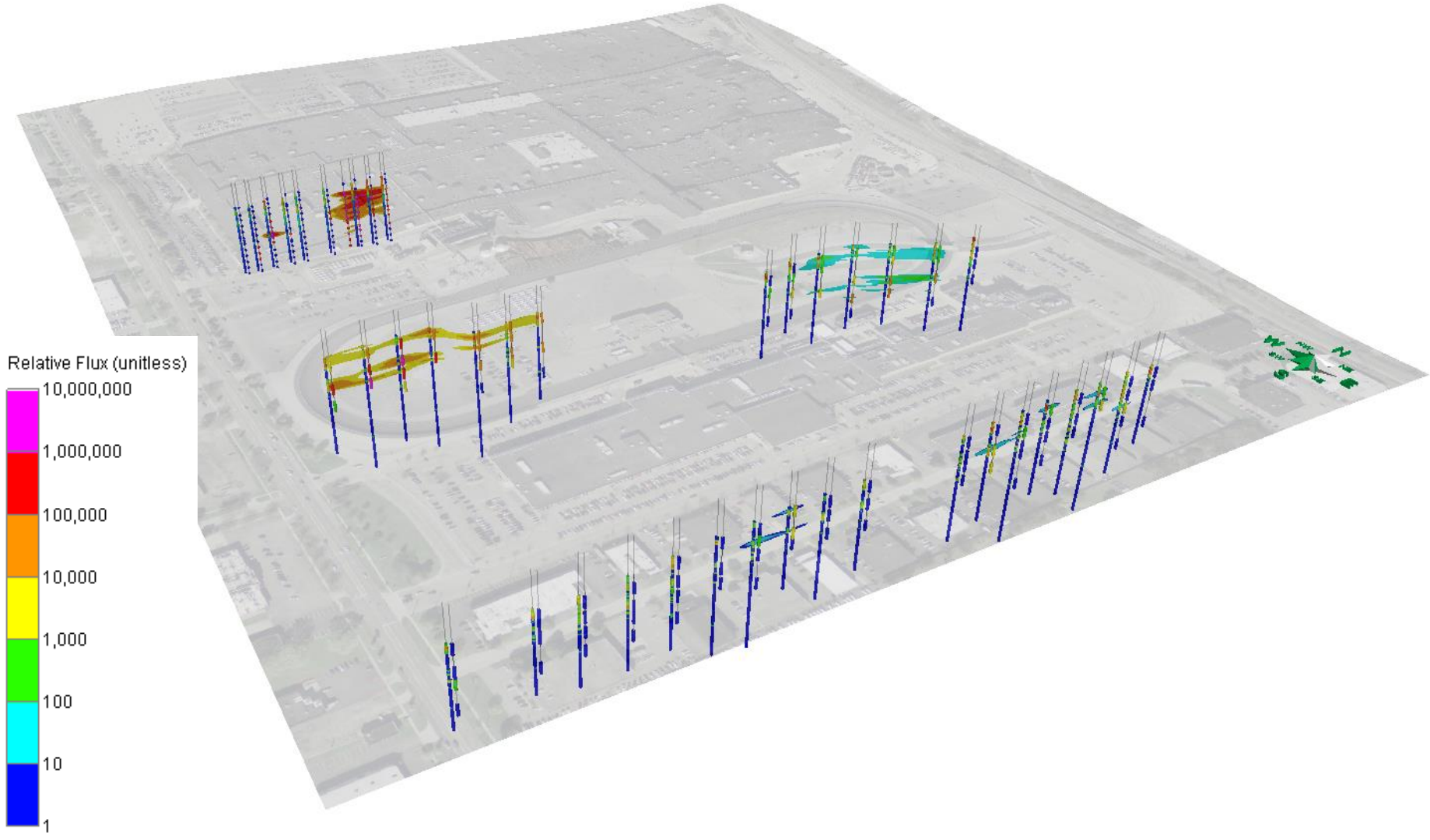
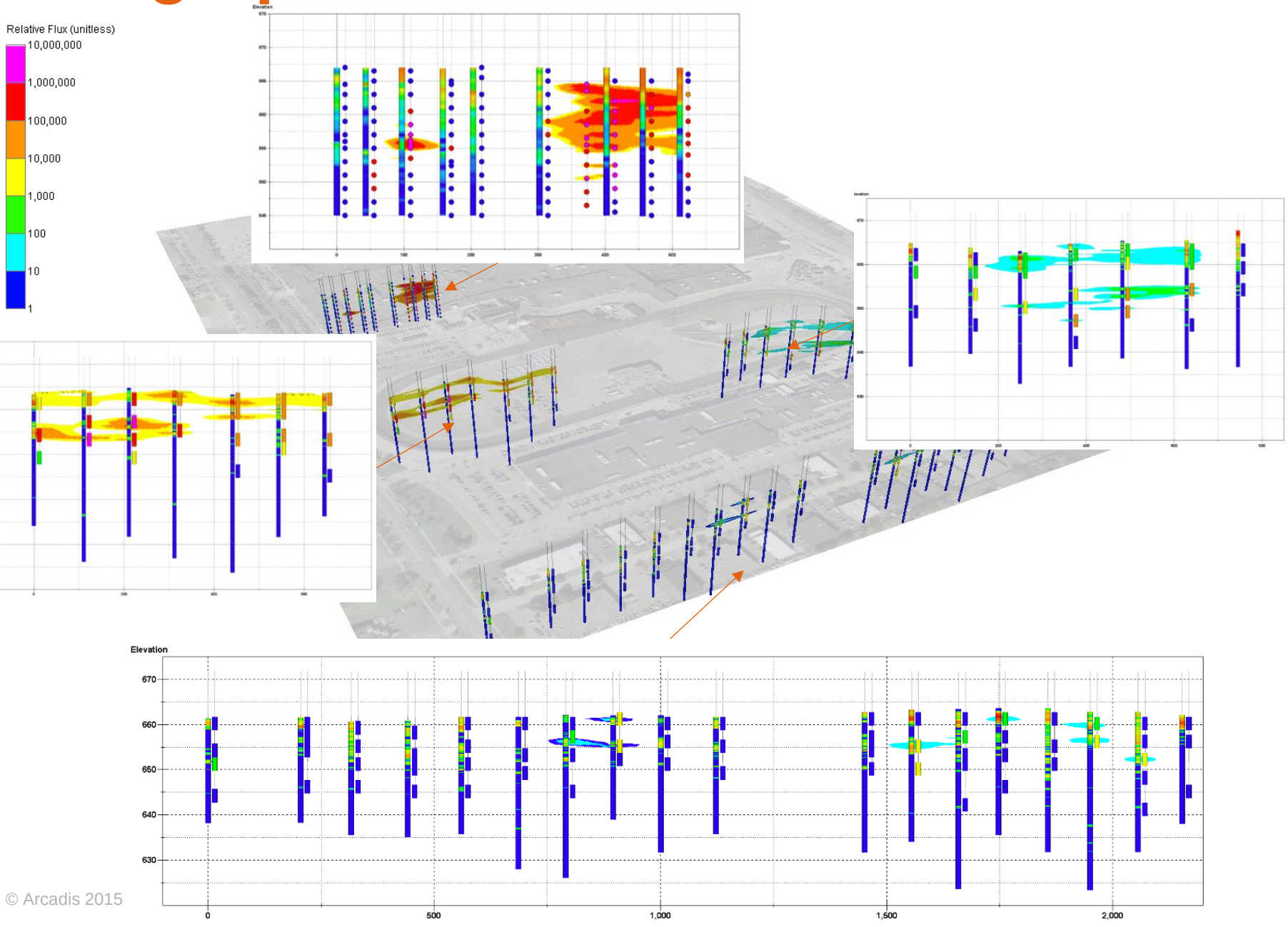
Case Study: 3D Stratigraphic Flux

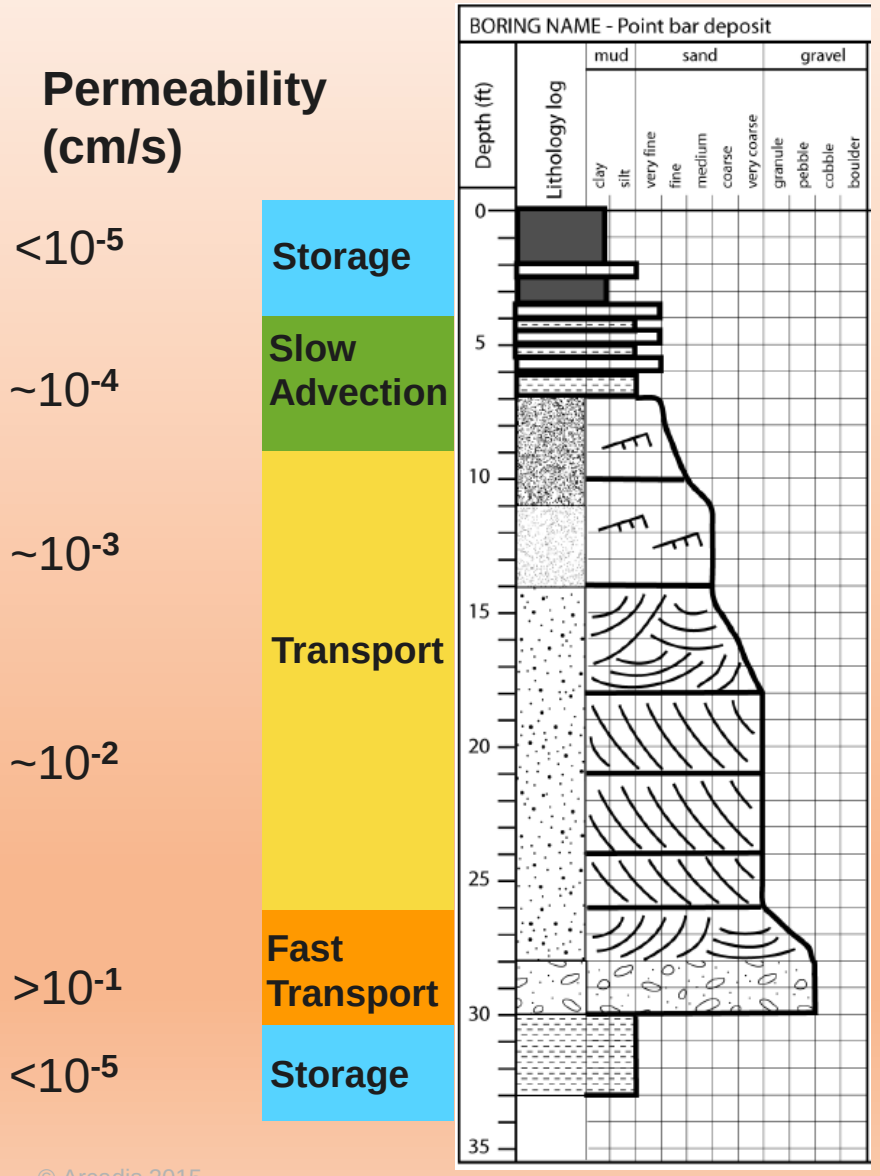
Multliple Transects



Stratigraphic Flux Model



Summary

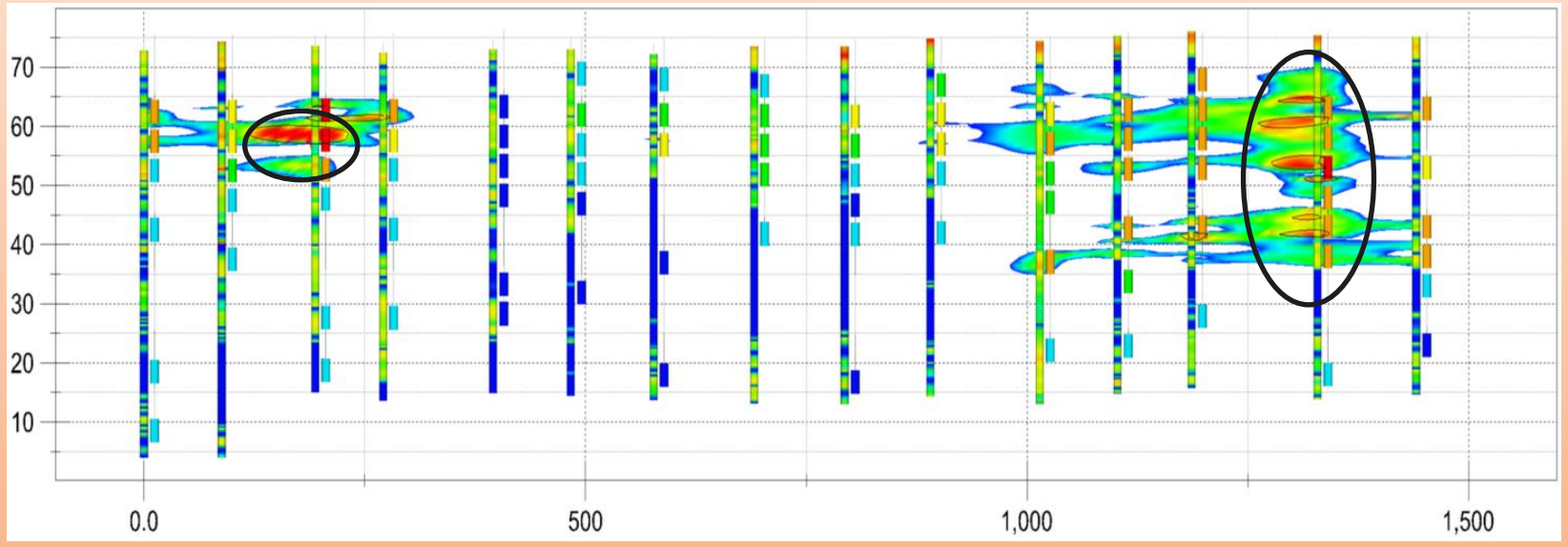


Hydrofacies mapping & hydraulic profiling provide key advantages:

- Relative K can be displayed graphically, or interpreted in 3D model
- Allow for stratigraphic correlation and mapping of permeable zones
- Methods readily distinguish transport zones from storage zones - “stratigraphic flux”

Summary

Stratigraphic Flux:
Focus the evaluation on zones that transport mass



Focus on the Mass that Matters

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Thank you!

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